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SPEECH REINFORCEMENT TECHNIQUES IN CHURCHES AND CATHEDRALS

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INTRODUCTION

A popular text book on architectural acoustics [1] includes the following observation on this subject:-

> "Probably the worst buildings for speech are large churches and cathedrals. Their reverberation times are long and the distances to be covered by the loudspeakers are great. Further, the system has to work not only when there is a full congregation but also when the floor area is only sparsely covered."

This short extract reads as a robust description of a thoroughly hostile acoustic environment. The only significant omission would appear to be high levels of intruding or background noise which can also occur from time to time - particularly during family services!

The architectural form of the traditional church building can be traced back through tens of centuries and has its origins in very different social, cultural and ecclesiastical times. Today this architectural form serves at least two conflicting acoustic requirements. On one hand it is the vehicle for a vast heritage of religious and secular music that was composed for and virtually demands the blending and sustaining provided by a long reverberation time - a requirement that has endured since the era of the plainsong chants - while on the other hand there is also a teaching role which requires clear delivery of the spoken word without the obscuring effect of reverberation.

This latter requirement is the result of a long development in the usage of this type of building. Gone now are the days when the proceedings were sung in a foreign language all children had to learn their catechism by heart before they could be accepted as full members of the Church. The congregation is now expected to take a much greater part in the service and the preaching is intended to be educational. The spoken word must be intelligible.

THE NATURAL ACOUSTICS

The typical arrangement of a church, its physical and architectural features and the distribution of the sources and listeners within the space make very important contributions to the natural acoustics of the building. An appreciation of these features and how they affect the transmission of sound within the space is particularly important in the assessment of how the acoustics could be enhanced.

Sanctuary - The area reserved for the clergy and usually a long way from most of the congregation. This area was visually important as it highlighted the dramatic elements of the service and the segregation of the clergy from the laity. The acoustic remoteness was not too important as the same words

would be used every week and most people probably knew them off by heart.

Lectern - normally at the boundary between the area reserved for the clergy and the seating for the congregation. Those who wanted to hear would probably choose to sit at the front. For those further back, they would probably have heard the readings before and would be able to make out the words even if the articulation was poor.

Pulpit - can be up to halfway down the main seating area for the congregation and raised substantially above them to give the preacher the best chance of projecting his voice to all corners of the building. The construction may well incorporate a reflective canopy above the preacher to further assist projection. There has, however, been a trend of late to remove these overpowering monumental edifices and to compromise the acoustic advantages that they once offered.

Choir - the area reserved for the choristers is almost always tiered and often raised up to improve the projection of sound. Their positioning may well take advantage of particularly favourable propagation characteristics of the space, perhaps the culmination of experience amassed over many centuries.

Organ - A powerful acoustic source within the space. It is almost invariably positioned in a prominent (even dominant) position and elevated to assist the projection of the sound to all parts of the space. The instrument, or perhaps just a part of it, will be closely associated with the choir to overcome time delay problems in the arrival of sound from the two sources.

Cathedrals usually take the form of an aggregation of two or more spaces (commonly referred to as Nave and Quire) which may be physically divided by substantial screens. Each of these spaces would be loosely based on the arrangement described above and they would perform acoustically in much the same way. Taken together, however, the coupling between the spaces leads to significantly increased volumes and much larger reverberation times. The individual spaces are then used for particular services according to their size and character. There are relatively few services in the church calendar which make use of more than one of these spaces. These big services usually require special consideration to solve (or at least provide the best compromise for) the acoustical problems. By way of example those who watched the recent wedding of the Duke and Duchess of York at Westminster Abbey may well have noticed that the choir and other musicians were not positioned in their normal seats, but were placed on top of the screen between the Nave and the Quire so that they could project equally into both these spaces. A more conventional solution is to arrange the order of service so that the choir and clergy process from one space to the next during the service so that the members of the congregation in each space are directly involved in at least a part of the service.

These features, related to the building itself and its usage, determine how well unaided speech will propagate in the space but the performance of the speaker is vitally important. In this respect there has been a decline in standards in recent times. The clergy are no longer given the training in projecting their voices that they were once subjected to nor are the candidates for a post as Canon in a Cathedral required to take an audition to

ensure that they would be heard at the west end of the Nave! There are exceptions of course but generally the musical traditions have been retained with maintenance of the large volumes and hard surfaces to achieve a long reverberation time. All of the compromise has therefore had to be made by the spoken word and this has led inevitably to the increasing use of electro-acoustic systems in churches.

ELECTRO-ACOUSTIC CONSIDERATIONS

The nature of this type of space is such that it is not just a matter of dangling a few big loudspeakers on the walls and hoping for the best. Systems are becoming more sophisticated and the expectations of congregation and clergy alike are rising with every new day's exposure to high quality broadcasts and recorded sound. "If a record can sound so good in the living room why can't it sound just as good in the church?" is a frequent question. The answer is inherent in the different acoustic character of these two spaces. Good intelligibility relies on achieving a high level of direct sound compared with the reverberant levels. This is difficult to achieve in large reverberant spaces and when positioning the loudspeakers the most efficient coverage becomes especially important. At first sight it would seem that all problems can be solved by adding more and more loudspeakers to improve the direct sound but this is in fact counterproductive because every extra loudspeaker, although improving the direct sound in its vicinity, adds to the reverberant field also. As so often happens a compromise has to be established.

Loudspeakers

There are three distinct types of loudspeaker design that are usually used for Church and Cathedral speech reinforcement systems. These are a central cluster, a distributed system using conventional column loudspeakers and phased array columns. Whatever type of loudspeaker design is adopted the basic requirement is still the same. It must provide clear, intelligible speech reinforcement with minimal excitation of the reverberant space. There are advantages and disadvantages with each loudspeaker type. Spillage and overlap of coverage are generally the main shortcomings of distributed systems and on this basis alone the central cluster approach is difficult to fault. A central cluster usually consists of a combination of horn and boxed loudspeakers positioned at high level over the altar or sanctuary area. They are particularly useful in modern buildings such as Coventry Cathedral but both aesthetic and technical problems are encountered in older buildings. Few traditional churches are prepared to accept the suspension of a central cluster above the Sanctuary area. Whilst it may be possible to provide reasonable coverage throughout a typical Nave using a cluster, the screening effect of the Nave columns will markedly affect intelligibility in the side aisles. Normal column loudspeakers can be used as a complete alternative or can be used to provide fill-in coverage in difficult areas. Column loudspeakers can also be aesthetically unacceptable as they have to be angled away from the supporting column to direct their beam down onto the congregation in order to provide good coverage and control of the reverberant field. Phased array column loudspeakers that can be positioned hard against the supporting column whilst still achieving a downward radiation pattern are both technically and aesthetically acceptable but are relatively expensive.

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A distributed system can be configured in such a manner that only the occupied areas within the space are provided with a reinforcement signal, the loudspeakers in other areas being switched off from the control position, avoiding unnecessary excitation of the reverberant space. If it is considered desirable to overcome the image shift problem (known as the Haas effect) when using a distributed system then it is usually necessary to use delayed feeds to the loudspeakers, while a well positioned cluster usually requires only a single, undelayed feed. There are no clearly definable guidelines that enable a choice to be made between the various types of loudspeaker systems available. Experience has shown that distributed systems using column loudspeakers are generally adopted on the grounds that they can be both aesthetically acceptable and provide the consistent means by which all areas within the Church or Cathedral can be provided with reasonable sound reinforcement.

System Operation

The development of an effective technical approach to the design of sound reinforcement systems in Cathedrals is based on the primary requirements of simplicity of operation, reliability and system versatility. Much of its success will also depend on how the system is operated. A Cathedral represents a significantly more hostile acoustic environment than say a theatre or conference centre yet it is still very unusual to have a committed sound system engineer in attendance, the popular approach being to delegate the work to the verger who owns the most sophisticated hi-fi system! The ability therefore to make complex alterations to system balance, equalization, coverage, gain etc. during a service is not generally available and compromise solutions are inevitable. Some degree of control will, however, almost always need to be provided. In its simplest form this will be just a master volume control. Despite compromises the basic design objective of 'greatest intelligibility for the greatest number' must be met.

One of the most commonly encountered problems in Cathedrals is the relationship between system gain and the number of microphones that can be used at any one time. It is not unusual to have as many as six or more microphones positioned around the Sanctuary area, with the likelihood that most will be required at some time during the service. However, it is unlikely that more than one will be required at any one time. The probability of feedback occurring is greatly increased when a number of microphones are simultaneously 'live'. This is particularly so in a very reverberant Cathedral environment.

User discipline within Churches and Cathedrals is generally very high and for this reason it is possible to incorporate a number of semi automatic control facilities that can simplify system operation and rationalize microphone selection. Four basic approaches to microphone selection can be identified.

1) User controlled with a simple on/off switch fitted to each microphone. This is the most inexpensive solution which when used correctly can be quite satisfactory, particularly for relatively simple installations. The basic disadvantage is that the user may well not remember to turn off a microphone after use. In this way it is possible to have a large number of microphones potentially live at the same time and this can give rise to feedback, forcing the system gain to be reduced to accommodate the extra input.

2) User controlled with a 'logic send' pulse system incorporated via a switch at each microphone location. Circuitry at the amplifiers then decodes this signal and performs appropriate switching of the microphones. This system can be extended to include automatic loudspeaker switching and other signal routeing variations determined by the microphone in use. It is possible for example to arrange that no two microphones are live at any one time and that apparent source positions are maintained by suitable alterations to the delay feeds to a distributed loudspeaker system. The principle disadvantage of such an approach is the added system complexity (and cost) but there are significant benefits for the user.

3) Microphone automatic mixer incorporated into the system. With these devices the microphones are automatically turned on when their input level rises above a preset threshold. The overall system gain is also reduced by a predetermined amount if more than one microphone is live at any one time. Such an approach can be very appealing as it avoids the need for any operator or user controls other than perhaps a master volume control. The main disadvantage (other than cost) is that secondary pickup via unused microphones can result in system gain being reduced at times when a gain reduction is not necessarily justified. Theoretically this is unlikely to occur to a serious extent in most normal applications but the very reverberant conditions that prevail in Cathedrals can give rise to a multitude of confusing conditions that can confound 'automatic' microphone mixers.

4) The final option is to commission a sound engineer to operate a mixer console throughout the service and be responsible for signal routeing, level, balance etc. This still has to be considered the most satisfactory approach as unforeseen problems or contradictory requirements can be dealt with depending on particular circumstances. It is however still possible for operators to make mistakes (sometimes disastrous) and complex signal routeing changes may be impractical without some measure of automatic control. The operator need not be a member of staff. At least one Cathedral has a rota of members of the congregation who operate a mixer desk for virtually every service.

Microphones

In an effort to minimise the problems associated with feedback it is usual to use microphones that have a directional response, cardioid and sometimes hyper-cardioid designs being the most commonly used transducers. Alternative technical solutions to the feedback problem are always worth considering though they are rarely deemed acceptable by the clergy. A rather neat solution to the feedback problem would be to use throat microphones or close proximity lip microphones at critical locations and to ensure that any potentially live microphones in other positions are located well away from designated loudspeaker coverage zones. Not surprisingly there has been almost universal opposition to any special arrangements that require 'hidden' microphones to be fitted prior to the beginning of the service. Strangely however there is a growing interest in the use of radio microphones so perhaps less orthodox alternatives may be found to be gradually more acceptable in the future.

Radio microphones are certainly useful in allowing freedom of movement and operation remote from any convenient microphone sockets but they do have a tendency to highlight the basic shortcomings of speech reinforcement systems.

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Aside from the well known problems associated with rf interference, signal cut-out and battery life, radio microphones can on occasions be located at unfortunate positions in the Cathedral at which particularly intense antinodes are present. The likelihood of feedback occurring at these locations is greatly increased though it is virtually impossible to anticipate in advance when potential problems will arise. It is not unusual to find users positioning themselves directly in front of system loudspeakers when using radio microphone sets, and then blaming the resulting feedback on some kind of system malfunction. Radio microphones must be used with caution and the user must be relied upon to impose some of the discipline that would be inherent with a trailing cable or a fixed microphone. Virtually all radio microphone packs are fitted with omni-directional microphones and on a simple comparison basis the gain before feedback is less than that achieved using cardioid microphones or a directional Lavalier microphone. On the positive side the radio microphone packs fitted with Lavalier capsules do ensure a fixed and constant distance between the microphone capsule and the user's mouth and if used prudently they can be of great benefit in simplifying the technical requirements during large services. Another problem with radio microphones, peculiar to their use in Churches, is that some of the vestments that are worn can contain very significant quantities of gold thread which can act as a very efficient radio frequency screen between transmitter and receiver.

A radio microphone set does not lend itself easily to the user controlled 'logic send' pulse systems described above. For this reason it is often arranged that remote radio microphone control facilities are provided that select the radio microphone signal when required, configuring the system to an operational status that meets the requirements of the radio microphone when used at its most popular location or locations.

Other System Enhancements

In Cathedrals it is often a requirement that services conducted in the Nave be audible in the Quire and vice-versa. In some instances the singing from the choir (in the Quire) has to be relayed via 'music' microphones to the Nave sound system, because the screen between the Nave and Quire significantly affects the natural propagation of sound. Under these circumstances it may be argued that a delayed feed is required from Quire to Nave to compensate for time of arrival differences between the relayed signal and the natural signal from the Organ (usually located near the choir) and to a lesser extent the singers themselves. In practice the sound from the Nave system tends to make its way back to the Quire at a level which varies depending on the size of the congregation in the Nave. If a delay is fitted between the Quire and Nave then the returning signal from Nave to Quire is far too delayed for a soloist to tolerate and only serves to generate further reverberance. The compromise solution is usually to provide a degree of control over the level of 'music' signal heard in the Nave (adjustable in the Quire) and to omit delays unless there is a direct line of sight contact, as is the case for those Cathedrals without a screen separating the Nave from the Crossing. An alternative solution is to fit music loudspeakers on top of the screen to provide a subtle lift in perceived level in the Nave area.

Other electronic techniques are also available to improve and enhance the performance of sound reinforcement systems in Churches and Cathedrals, the

logic control systems described above for automatic mutually exclusive microphone selection and signal routeing being a good example. Whether or not it is necessary, in the context of church sound systems, to go to the cost and complexity of incorporating delay lines to prevent the acoustic image shift from the true source to the nearest loudspeaker is a matter of considerable debate. They are certainly effective in overcoming the Haas effect but in some cases it is possible to reduce the need for such delays by careful loudspeaker placement. The sound from distributed loudspeakers can confuse intelligibility but if it is arranged that each loudspeaker provides coverage over a carefully defined listening area then the requirement for signal delays is significantly reduced. The image shift problem still remains however though in many instances this is of little importance, the main requirement being that the reproduced signal is clearly intelligible. If a delay system is installed then it poses great problems when microphones are used other than in the Sanctuary. For example, a microphone used at the west end would require the whole delay system to be turned round to allow sound to appear to propagate in the opposite direction. Radio microphones provide further problems because, by virtue of the mobility that they give, they may be used in positions which are at odds with the apparent source position defined by the time delay arrangement. Time delay systems can be provided but they add greatly to the overall system complexity. They would normally be incorporated with a 'logic send' microphone selection system so that each individual microphone would, according to its priority, arrange the appropriate delayed feed to be routed to the various system loudspeakers.

Graphic equalizers can play a useful part in enabling a neutral well balanced signal quality to be achieved and, of course, to provide the bass cut that is normally necessary in such reverberant conditions. If the system is to be used only for speech then a graphic equalizer can make quite significant changes to the spectral content of the reproduced sound. In this way improved speech intelligibility can be traded off against reduced fidelity though this should be regarded as a last resort rather than a design aim. It is tempting to overcome feedback problems by adjusting the equalization such that the loop gain is reduced at the frequency of feedback. One-third octave graphic equalizers certainly enable this to be done but the bandwidth of each element of the equalizer is too wide for any large alterations in system equalization to remain unnoticed, and for this reason only limited control of feedback is available. If feedback suppression is particularly desirable then notch filters can be considered. Frequency shifters can also be used with some success to control feedback with the spoken word but are generally unsatisfactory when used for singing, an important consideration when dealing with sound reinforcement in Cathedrals. Even small changes in signal frequency can be readily detected by trained singers and can play havoc with their pitch control.

Induction loop systems for the hard of hearing are now beginning to play a major role in sound system installation and these provide an effective and inexpensive aid for people using hearing aids.

EDUCATION

Educating people in the techniques of using any speech reinforcement system is particularly important. Some guidance is published by the Church on

ncorporating sound systems into its buildings [2]. However, it has to be mpressed upon the clergy that a speech reinforcement system is a tool that an help them but it has to be used correctly and this may require them to idapt their presentation. For example it has been found that it can be lifficult to make them move to a microphone when they are going to speak. The Sanctuary is the area that will contain many of the microphones and have the most limited loudspeaker coverage. For this reason it must be accepted that it is going to become the area in the building where it is hardest to hear, rather than the best area as would be the case when relying only on the natural acoustics. Guidance on how to use an electro-acoustic sound system should form part of the instruction manual and it must be made clear to everyone that a well designed speech reinforcement system can only reproduce what is put into it. Even the very finest sound system cannot improve the quality of a bad speaking performance, it can only reproduce it faithfully.

CONCLUSION

A simple rational approach to system design in Churches and Cathedrals usually gives the best results. It is always advisable to distribute the loudspeakers so that maximum coverage is achieved with minimum overlap. Sensible system equalization is advisable to avoid unnecessary excitation at low frequency. Careful placement of microphones (preferably behind or well away from any loudspeakers) avoids major feedback problems. On those rare occasions when a microphone has to be positioned close to a loudspeaker, automatic muting of the loudspeaker should be provided when the microphone is enabled. System complexity should be reduced to a minimum consistent with the basic requirements of the Church. It is always tempting to add additional complexity to overcome certain problems; in some cases this is justified but more often than not it will only compound the problems. Reliability is of paramount importance and this has to be a major consideration when designing speech reinforcement systems for ecclesiastical buildings. The unusual requirements of Cathedral sound systems, for example the relay of music from Quire to Nave, must be considered from the standpoint of both the users and the listeners.

It is sometimes easy to be carried away by system technology and forget the feelings of the clergy and other staff. The principle requirements from the Church's viewpoint are that the system must be reliable, effective, simple to operate and inexpensive. Aesthetic considerations are often a major design factor. It is a sad reflection that on rare occasions the aesthetic constraints on the disposition of loudspeakers and other system hardware can take precedence over the requirement for good speech intelligibility. Most people are however very aware of the acoustic problems within Churches and Cathedrals and are increasingly prepared to tolerate electronic gadgetry in the interests of improving speech intelligibility.

REFERENCES

[1] Acoustics, Noise and Buildings: P H Parkin, H R Humphreys and J R Cowell: Faber 1979.

[2] Sound Amplification in Churches: Jennifer Zarek: Council for the Care of Churches 1983.